Assessing semantic network integrity via the word-picture verification paradigm: Evidence for shared input and output lexical-semantic abilities

Research Thesis

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Table of Contents

Tables and Figures

1. Abstract

There has been disagreement in the literature about whether semantic information is processed by a single or multiple semantic systems. Lexical-semantic processing is frequently assessed and often impaired in aphasia, an acquired language disorder commonly occurring after a stroke or brain injury. The purpose of the current study is to partially replicate Hillis, Rapp, Romani, and Caramazza's study (1990) to ascertain whether their findings, in support of a single semantic system, would be generalizable to a larger group of individuals with varying types of aphasia. It is hypothesized that a uniform error pattern across input and output lexical-semantic tasks will be observed, supportive of a single modality-independent semantic processing system.

Twelve individuals with aphasia completed confrontation naming and auditory and reading word-picture verification tasks as part of a larger study. The study revealed no significant difference in semantic errors on these two tasks despite the differences in modality. This uniform error pattern across comprehension and production tasks lends continued support to Hillis and colleagues' Organized Unitary Content Hypothesis (O.U.C.H.), suggesting that there is a single semantic system accessed during language processing. Clinically, these findings could help inform decision making with patients with aphasia and motor speech deficits by helping to identify locus of impairment. However, continued investigation is needed to shed more light on how exactly WPVTs can be used in speech-language therapy for aphasia.

2. Introduction

2.1. Background on Models of Semantic Processing

The existence of a unitary modality-independent versus multiple modality-dependent semantic processing systems has been disputed for decades amongst language researchers. There has been disagreement in the literature about which of these semantic models the evidence best supports. Some studies (e.g. Caramazza, Berndt, & Brownell, 1982; Jackendoff, 1987; Riddoch, Humphreys, Coltheart, & Funnell, 1988) support the modality-independent theory, in which semantic information is stored in an amodal hub, and still others (e.g. Paivio, 1978; Shallice, 1987; Warrington, 1975) favor the modality-specific view, in which semantic information is stored in separate modality-specific hubs.

In a case study by Hillis, Rapp, Romani, and Caramazza (1990), the researchers hypothesized that there is a single, unitary system for processing semantic information regardless of input or output modality (e.g., written, oral, tactile, etc). Hillis and colleagues posit that their findings support the Organized Unitary Content Hypothesis (O.U.C.H.; e.g., Caramazza, Hillis, Rapp, & Romani, 1990), which states that there would be only one modality-independent conceptual system accessed during any task that involved processing semantic information, regardless of how the information was expressed or received. O.U.C.H. is in contrast to the opposing view that there are multiple, independent systems for processing the semantic information from each modality separately (e.g., Shallice, 1987; Warrington, 1975). For example, this opposing view would suggest that if an individual was asked to name a picture verbally and then was asked to name a picture by writing, the systems engaged to process meaning during these different tasks would be completely separate and independent of one other. Riddoch and colleagues suggest in their 1988 study that an implication of Shallice (1987) and Warrington's (1975) work on modality-dependent semantic systems is that conceptual semantic information can actually exist in these multiple systems simultaneously, despite being accessed separately (Riddoch et al., 1988). Thus, if an individual asked to produce the name of a picture verbally responded with a semantically-related incorrect response and correctly wrote the picture name, an argument for modality-dependent semantic systems could be made.

In Hillis and colleagues' (1990) case study of the individual KE, the investigators discovered a uniform semantic error pattern across tasks that assessed different input and output modalities. This error pattern suggested damage to a single, modality-independent semantic processing system responsible for all lexical processes (Hillis et al., 1990). In other words, if there was a single mechanism in the brain intended for processing all semantic information, regardless of the manner in which it was comprehended or produced, then it would make sense that damage to this common mechanism would cause the same errors to be made across all modalities. Based on these data, it would be difficult to argue for the opposite view of multiple separate semantic processing systems because that "would require that each of the putative systems or mechanisms be damaged in an identical manner", which the investigators concluded would be very difficult to explain (p. 220; Hillis et al., 1990). The investigators do mention the assumption of privileged accessibility (Caramazza, Hillis, Rapp, & Romani, 1990; cited in Hillis et al., 1990) wherein different types of perceptual information, such as words and objects, have unequal access to modality-independent semantic information, which may result in performance that appears to support modality-dependent semantic systems but in actuality reflects impaired *access* to modality-independent semantic information.

Many tasks were employed to assess KE's semantic processing performance, but two tasks that will be of focus in the current paper include a confrontation naming task (i.e., verbal production of the presented picture) and word-picture verification task (WPVT). The WPVT entailed the presentation of a word and a picture, and KE was instructed to either confirm or reject agreement between them. The words were presented to KE either auditorily or orthographically along with the picture. For both the auditory and written WPVTs, the target picture name was presented once with the correct picture, once with a semantic foil (i.e., an incorrect picture that is semantically-related to the target, such as *tiger/lion*), and once with a control foil (i.e., an incorrect picture with a name visually and/or phonologically similar to the target, such as *tiger/timer*), each on separate trials. For example, if the target was *tiger*, KE would have to correctly endorse a match when a picture of a tiger was shown and reject the match when a picture of a lion and a (kitchen) timer were shown. An item was only scored as correct if KE confirmed the correct picture name *and* rejected both the semantic and control foils. In other words, KE was only correct if he confirmed that the picture was of a tiger and also rejected that it was a lion or a timer.

The investigators assert that all knowledge about semantic properties of a word are stored in an amodal format and can account for patterns of selective damage (Caramazza et al., 1990). O.U.C.H. states that all information that contributes to the meaning of a word, such as perceptual properties of the referent (e.g., shape, color, or parts), functional properties of the referent (such as actions or purpose), or information about how that word relates to other words is stored in a dedicated semantic space (e.g., Hillis et al., 1990). All of this semantic information can be accessed through the phonological lexicon (i.e., from auditorily-presented words) or the orthographic lexicon (i.e., from visually-presented words), but the ultimate semantic information accessed by both is exactly the same (e.g., Caramazza et al., 1990). Access to semantic information from objects/pictures has more privileged access compared to words (e.g., Caramazza et al., 1990). Hillis and colleagues hypothesized that the pattern of selective semantic damage seen across modality in their case study resulted from only some of the semantic representations of an item being accessed. In other words, information about some of the properties normally used to distinguish semantically-related items was incomplete or not fully formed (Hillis et al., 1990). This would explain the frequent coordinate semantic errors (i.e. words in the same semantic category) KE made across all modalities; incomplete access to all the necessary information about any given word would make it difficult to distinguish semantically-similar or related words (i.e. a tiger and a lion) despite the context in which it was presented.

However convincing Hillis and colleagues' evidence is, it is nonetheless true that evidence in support of O.U.C.H. was gathered from a single case study. It remains unclear if these findings could be generalizable to a larger sample size, or for participants with varying types of aphasias. Additionally, Hillis and colleagues conducted their investigation using varied pictorial stimuli, thus limiting the investigation to only semantic abilities. Picture stimuli that are more consistent (i.e. varying the lexical stimuli instead) may elicit stronger evidence of lexical-semantic abilities.

2.2. Purpose of current study

The purpose of the current study is to perform a partial replication of Hillis, Rapp, Romani, and Caramazza's study (1990) to ascertain whether their findings of support for an amodal semantic system accessed by production and comprehension processes will be generalizable to a larger group of individuals with varying types of aphasia. The current study extends the work by Hillis and colleagues (1990) in a few ways. First, the current study includes an extra linguistic foil (i.e. unrelated foil) so that a larger variety of word-picture pairs are assessed and to provide a control condition. In addition, Hillis and colleagues varied the pictorial stimuli (e.g. showing pictures of a tiger, a timer, and a lion for target word *tiger*), whereas the current study varies the linguistic stimuli (e.g. showing the words "tiger", "timer" and "lion" for target word/picture *tiger,*) to assess semantic processing abilities in word-picture pairs, thereby attempting to provide insight into lexical-semantic rather than solely semantic abilities.

To further investigate the existence of a single modality-independent semantic system, the current study compares performance on a confrontation naming task with auditory and reading nonverbal word-picture verification tasks (aWPVT and rWPVT, respectively). Since naming requires motor speech involvement and verification does not, it is expected that overall accuracy on naming and verification tasks will differ. If there is a single modality-independent semantic system, then the proportion of semantic errors will not differ between naming (output process) and verification (input process) tasks.

3. Methods

3.1. Design

This study used a within-group comparison of task (naming (BNT) vs. verification (aWPVT, rWPVT)) among individuals with aphasia. Two separate analyses were employed to investigate overall accuracy (percentage) and rate of semantic errors (percentage) across tasks.

3.2. Participants

Twelve adults (ten men and two women) with aphasia participated in this study. The participants varied in age (M = 61; SD = 14.91; Range = 36-78), months post-onset of cerebrovascular accident (CVA)(M = 54.67; SD = 57.55; Range = 6-178), years of education (M = 15.25; SD = 2.598; Range = 12-20), and aphasia severity (M = 62.19; SD = 15.43; Range = 39-93.5)(see Table 1).

Participants were included in the study if they were a native speaker of English, were between the ages of 19-90, had a left hemisphere stroke (now stable with chronic symptoms), were 6 or more months post onset from their most recent neurological event permanently affecting the brain, had significant but not profound anomia (as indicated by a score of 4-44 on the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), had aphasia as determined by a Western Aphasia Battery Aphasia Quotient of less than 94.7, and demonstrated adequate auditory comprehension abilities as characterized by a score within two standard deviations of the mean. Participants were excluded from the study if they had severe-profound apraxia of speech as determined by blinded ratings from experienced speech-language pathologists, had severe depression (Beck et al., 1996), had any uncorrected hearing and/or vision problems, or had or was suspected of having any diffuse injury or disease of the brain.

Table 1. *Participant Demographics*

Participant	Sex	Months Post Onset of CVA	Years of Education	WAB Aphasia Quotient	Age in years
100	M	178	20	60	72
101	M	33	17	71.8	36
102	M	14	12	57.4	62
103	M	44	18	54.8	36
104	F	12	14	63.8	40
105	M	21	14	76.5	67
106	M	154	17	93.5	63
107	M	6	13	52.2	70
108	F	74	12	39	78
109	M	27	16	54.1	69
110	M	82	13	45	72
111	M	11	17	78.2	67

CVA = cerebrovascular accident

WAB = Western Aphasia Battery

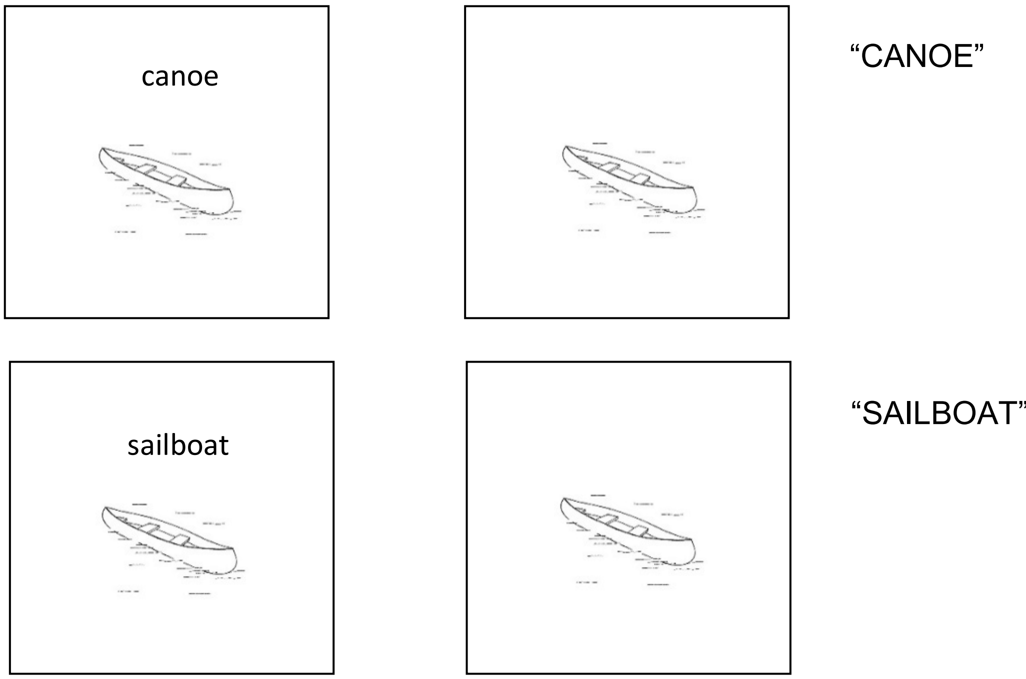
3.3. Stimuli

The BNT (Kaplan, Goodglass, & Weintraub, 1983) was used as a measure of lexical retrieval during verbal production. The BNT is an assessment of confrontation naming that includes sixty black-and-white pictures of objects ranging from high to low lexical frequency.

The computerized WPVTs required participants to judge whether a picture and a word presented simultaneously are congruent or incongruent via button-press. Pictorial stimuli were taken from the BNT and used with written permission. On the aWPVT, a picture was presented in the middle of the computer screen, and the word was presented auditorily by a female speaker at 70 dB SPL. The word was presented 25 ms after the picture; however, this seeming asynchrony was included so that the picture and the initiation of the auditorily-presented word appeared to occur simultaneously. On the rWPVT, a word was presented in all lower cases in size 36 Arial font just above the picture. The image resolution and size remained consistent across all stimuli and were displayed in the center of the laptop screen at a comfortable distance from the participant. WPVT stimuli were presented using E-Prime 2.0 software on 14-inch Dell Latitude E6430 or 15.6-inch E6540 laptop computers. See Figure 1 for an example of the WPVT.

The word foils (consisting of coordinate semantically-related words, phonologically-related words, and unrelated words) were all selected from the SUBTLEXus frequency database (Brysbaert & New, 2009). All pictorial stimuli and their correspondent target words were taken from the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983). Further details about stimuli selection and characteristics can be found in Zezinka (2017).

Figure 1: *Example of WPVTs*



Note: reading WPVT on left, auditory WPVT on right (Zezinka, 2017).

3.4. Procedure

3.4.1. BNT

For the confrontation naming task, participants were presented a picture and asked to name it to the best of their ability. Responses were scored as correct if the individual accurately produced the picture name independently or with a semantic cue. Minor distortions or addition/subtraction of the plural *–s* if it did not result in a change in meaning were considered correct. All other responses were scored as incorrect. Video and audio recordings of BNT performance were scored by author MN for overall accuracy and proportion of semantic paraphasias. Naming errors were considered semantic paraphasias if they shared a subordinate, superordinate, or associative relationship with the target picture name. Hillis and colleagues (1990) considered semantic errors "to be any response bearing a semantic relationship to the target: associative (pie → apple), superordinate (pie → dessert), co-ordinate (pie → cake), synonymic (pie → tart), etc." (p. 202; Hillis et al., 1990). Semantic paraphasias containing phonemic paraphasias (e.g. "seadull" for *pelican*; the semantic paraphasia is "seagull" for *pelican*, the phonemic paraphasia is "seadull" for "seagull") were also included in the count of semantic paraphasias, and circumlocutions were not included. Disagreements and/or questions in scoring the number of semantic paraphasia were settled by consensus with a graduate research assistant, AZ, and sometimes Advisor SH as well. Inter-rater reliability was calculated on 100% of overall accuracy scores on the BNT between MN and the examining speech-language pathologist. Reliability was found to be excellent as calculated via intraclass correlation coefficient using absolute agreement in a 2-way mixed effects model (ICC = .992; $F(11,11) = 234.93$, $p < .001$; 95% CI = [.973, .998]).

3.4.2. WPVTs

On the aWPVT, a picture was presented in the middle of a computer screen, and the word was presented auditorily only once. There was no time limit for participants to respond, so the picture remained on the screen until the participant responded via button-press. Participants were instructed to press the left arrow key for "yes" responses (i.e., if the presented word-picture pair were congruent) and the right arrow key for "no" responses (i.e., if the presented word-picture pair were incongruent). Visual cues of a red "x" for incongruent responses and a green check mark for congruent responses were used. This same procedure held for the rWPVT but with the exception of participants instructed that they would see a picture and a word on the screen at the same time. Both the word and picture remained on the screen until the participant responded via button-press. A blank screen was presented for 200 ms before the presentation of the next picture-word pair.

Across the two WPVTs, participants viewed a total of 480 word-picture pairs (60 picture stimuli in each of the 2 tasks, with 1 target word-picture pair and 3 foil word-picture pairs for each picture). Overall accuracy was determined using the following procedure; for both the aWPVT and rWPVT, the picture was presented on four separate trials: once with the correct picture name, and three times with foil words. A picture was scored as correctly "verified" only if the participant confirmed congruence with the correct picture name and the picture and rejected congruence with the three foil names and the picture. The WPVT semantic scores were determined by calculating the percentage of incorrect responses on semantic foils compared to the total number of distinct images (i.e., 60). For example, if a participant did not correctly reject the semantic foil presented with the picture on 20/60 possible distinct images, his or her semantic error rate would be 33% (20/60*100).

3.5. Analyses

Since the data were found to violate the assumptions of normality even after transformations were attempted, nonparametric analyses were conducted. Specifically, the Friedman Test was utilized to test for family-wise within-group comparisons. Pairwise comparisons were completed using Wilcoxon signed-rank tests with Bonferroni correction (corrected $\alpha = .01667$).

4. Results

Results revealed a statistically significant difference between BNT and WPVT overall scores ($X^2\,(2) = 10.61$, $p = 0.005$), indicating that participants scored higher on WPVTs compared to the BNT (BNT vs rWPVT: $Z = -2.654$, $p = 0.008$; BNT vs aWPVT: $Z = -2.858$, $p = 0.004$; rWPVT vs aWPVT: $Z = 0.204$, $p = 0.838$)

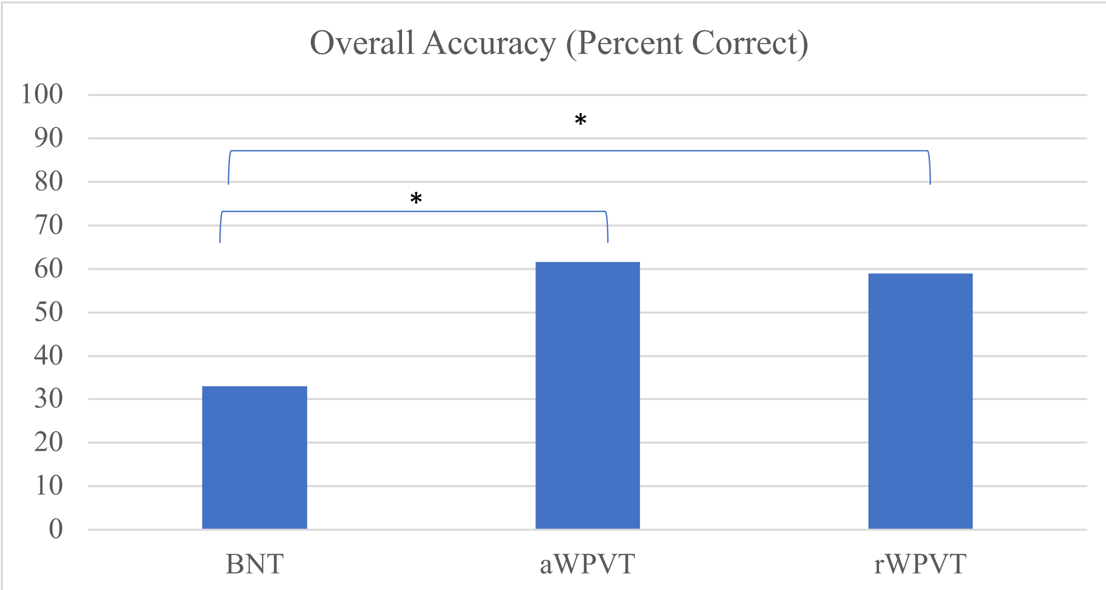
Results revealed no significant difference in semantic error rates between the BNT and WPVTs ($X^2(2) = 3.50$, $p = 0.17$). This finding suggests that the rate of semantic errors made on all three tests (aWPVT, rWPVT, and BNT) were similar across participants, despite the differences in input/output modality. Both findings were in line with the stated hypothesis.

Table 2*: BNT & WPVT Scores (Percent Correct)*

Participant	BNT Overall	BNT Semantic	aWPVT Overall	aWPVT Semantic	rWPVT Overall	rWPVT Semantic
100	23.33	0	68.33	15	88.33	1.67
101	55	18.33	81.67	16.67	85	11.67
102	10	3.33	28.33	41.67	10	65
103	28.33	26.67	75	21.67	28.33	28.33
104	16.67	15	83.33	11.67	90	5
105	63.33	10	83.33	5	71.67	23.33
106	66.67	8.33	78.33	11.67	68.33	13.33
107	11.67	1.67	21.67	33.33	83.33	13.33
108	16.67	5	1.67	63.33	10	53.33
109	11.67	5	71.67	20	30	60
110	25	6.67	55	16.67	68.33	13.33
111	68.33	11.67	90	8.33	73.33	21.67

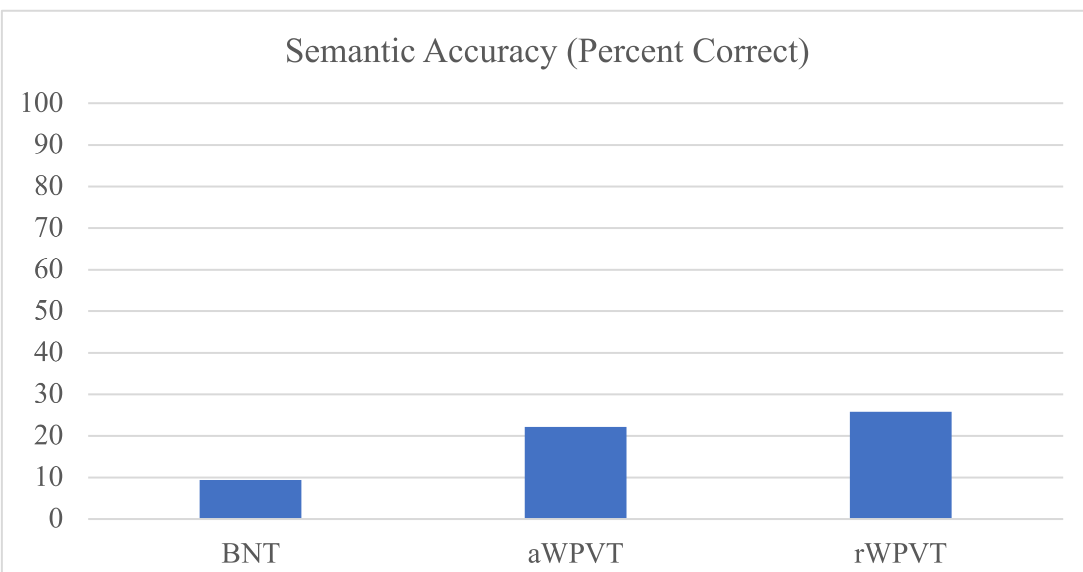
BNT = Boston Naming Test
aWPVT = auditory word-picture verification task
rWPVT = reading word-picture verification task
Note: all scores are out of a total of 60

Figure 2: *Overall Accuracy (Percent Correct)*



Note: * values significant at $p < 0.016$

Figure 3: *Semantic Accuracy (Percent Correct)*



5. Discussion

The purpose of the present study was to further investigate the integrity of the semantic system – whether there is evidence to support shared or separate networks for input and output lexical-semantic processes. The current study partially replicated Hillis and colleagues' (1990) work and extended their findings into a larger sample of individuals with different profiles of aphasia and by varying the linguistic stimuli paired with pictures. The finding of no significant difference between BNT and WPVT semantic error rates is in line with Hillis and colleagues' (1990) findings of uniform semantic error rates across input and output language tasks. This uniform error pattern across different comprehension and production-based tasks lends continued support to the O.U.C.H. (e.g., Caramazza et al., 1990), suggesting that there is a single semantic system accessed during language processing regardless of how that information is expressed or received.

Results of the present investigation also revealed a significant difference between overall accuracy on the BNT and WPVTs, which contradicts the findings of no significant difference in overall error by Hillis and colleagues (1990). The current study observed that WPVT scores were consistently higher than scores on the BNT. One possible explanation for this could be that semantic processing during verification tasks requires less cognitive demand than during confrontation naming tasks like the BNT, since verifying congruence may not require lemmas to be phonologically encoded and articulated like in confrontation naming tasks. In addition, the findings could also highlight differences in engaged processes – lexical retrieval vs. lexical verification/recognition. Another plausible explanation could be related to motor speech demand. If participants had more significant motor speech impairments, they may have made more incorrect verbal productions on the BNT, bringing down their score for that reason rather than deficits in lexical-semantic processing. Since the WPVT does not require verbal responses, the influence of motor speech ability is eliminated while assessing for lexical-semantic processing.

5.1 Limitations

There are a few limitations in the current study that should be considered. Namely, a lack of assessment of the participants' other components of language, such as phonological processing abilities or vocabulary size. Additionally, the participant sample was relatively small (consisting only of 12 participants), and only two of them were female. Furthermore, we only looked at one output processing task (oral naming) and two input processing tasks (auditory and reading), so our findings are limited to interpretations in these domains at the single word level. Further studies could compare writing as well and look more closely at individuals' premorbid reading, writing, and listening abilities to determine how those skills impact WPVT findings. Finally, further study of WPVTs is warranted to determine precisely what stage(s) or tasks WPVTs help to elucidate.

5.2 Clinical implications

Clinically, these findings could have far-reaching implications. For instance, if a patient is frequently making naming errors of a semantic nature, the O.U.C.H. could be used to inform clinical decision-making by leading clinicians to specifically target semantically-related words and strengthen word finding/naming skills in these areas. Additionally, these findings could lead clinicians to expect to see word-level errors in both understanding and production. Furthermore, these findings could help inform decision making when working with patients with aphasia and motor speech deficits by helping to identify locus of impairment. Patients may have difficulty naming objects in pictures, an assessment commonly used in aphasia therapy, because of motor speech, motor planning, and/or semantic or phonological language issues. Since our findings lend support to the theory that the same semantic system is accessed during word-level production and comprehension, WPVTs could be used in conjunction with picture naming to better understand semantic processing abilities since WPVTs do not require verbal responses, eliminating the motor aspect required in verbal naming.

6. Conclusion

In conclusion, the current study partially replicated Hillis, Rapp, Romani, and Caramazza's 1990 study in order to investigate whether their findings, in support of a single semantic system (i.e., O.U.C.H; e.g., Caramazza et al., 1990.), would be generalizable to a larger group of individuals with aphasia. The current study also built upon Hillis and colleagues' (1990) work by investigating more lexical conditions and incorporating a nonverbal response method to reduce the speaking demands on patients who typically have co-occurring motor speech impairments. Our results revealed a uniform semantic error pattern across comprehension and production tasks, lending continued support to a single modality-independent semantic system accessed during input and output language processing. Clinically, these findings could impact therapy methods for patients with aphasia and/or comorbid motor-speech impairments since our results suggest that WPVTs tap into the same semantic system as confrontation naming tasks. If a patient's language and/or motor impairments would have made assessing their semantic processing abilities difficult, a clinician could instead or in addition utilize a WVPT to assess semantic processing capabilities at the word level completely non-verbally. Continued investigation is warranted to shed more light on how exactly WPVTs can be used in speech-language therapy for aphasia.

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